THERMAL DESIGN & ANALYSIS OF SHELL AND TUBE HEAT EXCHANGER

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Abstract: The characteristics of heat exchanger design are the procedure of specifying a design, heat transfer area and pressure drops and checking whether the assumed design satisfies all requirements or not. The purpose of this thesis work is how to design the oil cooler (heat exchanger) especially for shell-and-tube heat exchanger which is the majority type of liquid-to-liquid heat exchanger. General design considerations and design procedure are also illustrated in this thesis. In design calculation, the HTRI code and Ansys software are used. Heat transfer concepts and complex relationships involved in such exchanger are also presented. The primary aim of this design is to obtain a high heat transfer rate without exceeding the allowable pressure drop. This HTRI code and computer package is highly useful to design the heat exchanger and to compare the design.
Within the project work , the thermal and pressure drop calculations are done by using the empirical formula, as per TEMA and verified with HTRI software package (USA)

Index Terms— FEA, ANSYS, TEMA,CATIA

1. Introduction

The science of thermodynamics deals with the quantitative transitions and rearrangements of energy as heat in bodies of matter. Heat transfer is the science that deals with the rate of exchange of heat between hot and cold bodies called the source and receiver. When one Kg of water is vaporized or condensed, the energy change in either process is identical. However, the rates at which either process proceed is different, vaporization being much more rapid than condensation.

The major difference between thermodynamics and heat transfer is that the former deals with the relation between heat and other forms of energy, whereas the latter is concerned with the analysis of the rate of heat transfer. Thermodynamics deals with systems in equilibrium so it cannot be expected to predict quantitatively the rate of change in a process, which results from non-equilibrium states. Heat transfer is commonly associated with fluid dynamics and it also supplements the laws of thermodynamics by providing additional rules to establish energy transfer rates.

Process heat transfer deals with the rates of heat exchange as they occur in the heat transfer equipment of the engineering process. This approach brings to better focus the importance of the temperature difference between the source and the receiver, which is, after all, the driving force whereby the transfer of heat is accomplished. A typical problem of process heat transfer is concerned with the quantities of heat to be transferred, the rates at which they may be transferred because of the natures of the bodies, the driving potential, the extent and arrangement of the surface separating the source and the receiver, and the amount of mechanical energy which may be expanded to facilitate the transfer. Since heat transfer involves an exchange in the system, the loss of heat by the one body will equal the heat absorbed by another within the confines of the same system

2. Types of heat exchangers (DG)

(i). AIR COOLED HEAT EXCHANGER

It is tubular heat transfer equipment in which ambient air passes over the tubes and thus acts as the cooling medium. Air is available in unlimited quantities compared to water. The airside fouling is frequent problem. But the heat transfer coefficient of air is less than that of water.

(ii). PLATE TYPE HEAT EXCHANGER

The plate type of heat exchanger consists of a thin rectangular metal sheet upon which a corrugated pattern has been formed by precision pressing. One side of each plate mounted on the frame and clamped together. The space between adjacent plates forms a flow channel. The cold and hot fluids flow through channels.

(iii). SHELL AND TUBE TYPE HEAT EXCHANGER

Shell and tube type heat exchangers are the most versatile and suitable for almost all applications, irrespective of duty, pressure and temperature. Shell and tube type exchanger consists of a cylindrical shell containing a nest of tubes that run parallel to the longitudinal axis of the shell and are attached to perforated flat plates called tube sheets at each end. There are a number of perforated plates, through which the tube passes called as baffles. This assembly of tubes and baffles is called a tube bundle and is held together by tie rods and spacer tubes for spacing the baffles.

Exhaust steam

Cooling water outlet
Cooling water inlet
To condensate pump
Tubes
Tube plates
Shell

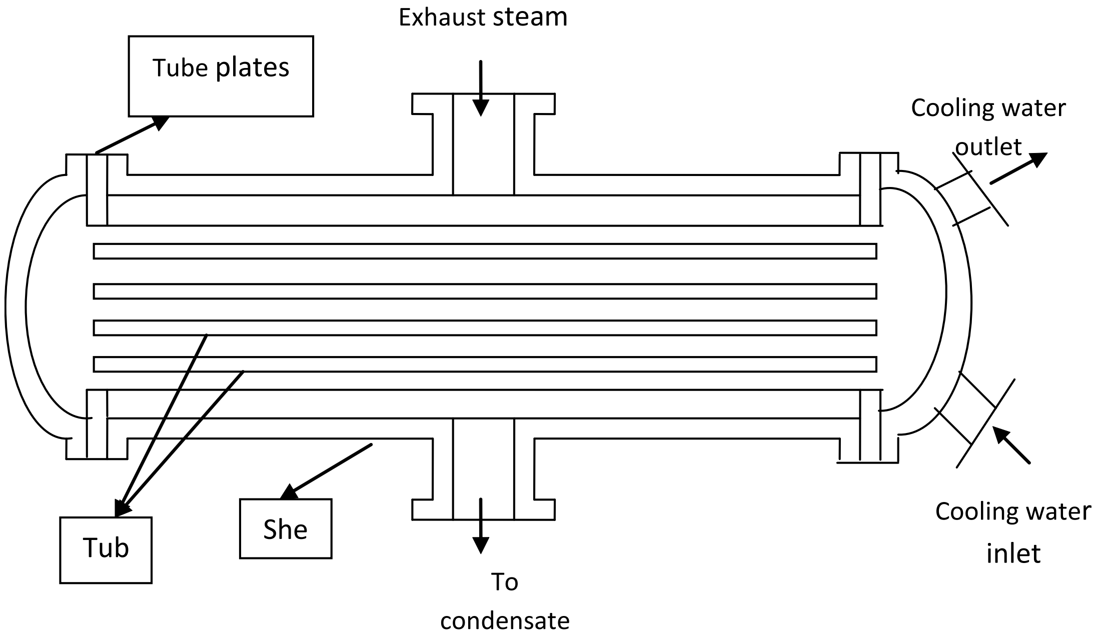


fig. A SHELL AND TUBE HEAT EXCHANGER

3. Design Methodoogy:

The first criterion that a heat exchanger should satisfy is thefulfillment of the process requirement. The design specifications may contain all the necessary detailed information on flow rates of fluids; operating pressures; pressure drop limitations for both streams, temperatures size, length and other design constraints such as cost, type of material, heat exchangers types and arrangements .The heat exchanger design provides missing information based on experience, judgment and the requirements of the customer.

The selection criterion is that the heat exchanger must withstand the service conditions of the plant environment therefore all thermal design analysis; the mechanical design is conducted, which includes the calculation of plate, tube, shell and arrangements. The exchanger must resist corrosion by the service and process streams and by the environment; this is mostly a matter of proper material selection. A proper design of inlet nozzles and connections, supporting materials, location of pressure and temperature and measuring devices and manifolds are to be made. Thermal stress calculation must be performed under steady state and transit operating conditions. The addition important factors to be considered are checked in the design are flow vibrations and level of velocities to minimize or eliminate fouling and erosion

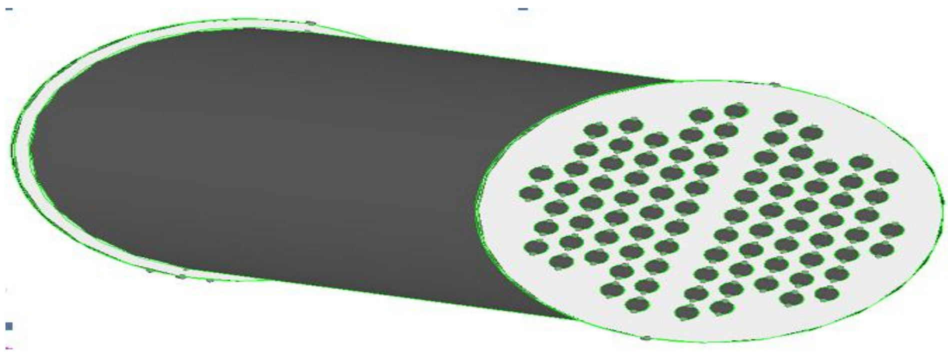
4. Modelling of heat exchanger using CATIA V5 R19 :

With the advances in computer technology and cad system, complex programs can be modeled with relative ease. Several alternative configurations can be tried out on a computer before the first prototype is built .of the various design packages available in the market , Catia is a parametric feature based package which is very flexible and versatile and hence is widely used .also it has an additional advantage of direct interface with a CNC machine.

It is one of the very few design packages which incorporates a wide range of modules required by the industry like :

- Sketcher
- Part drawing
- Advanced part
- Assembly
- Manufacturing
- Sheet metal
- Surface
- Drawing

In the present project, the components of heat exchanger are modeled using part drawing features and then using assembly modules, the assembly of the heat exchanger is generated. The part drawing is a versatile module where in the whole heat exchanger can be modeled as a single unit as opposed to the assembly module where each part is modeled separately and finally assembled to get the required component using the various options available. The geometric model of heat exchanger is shown in fig



5. Finite element method :

It is very difficult for human brain to examine critically the behavior of a complex structure subjected to different conditions. To overcome this, scientists started to divide the complex structure into individual components, whose behavior can be understood intuitively. This individual component is then assembled to study the behavior of the entire structure. This method of discretising a complex structure and then making analysis on it is termed as Finite Element Method.

The tendency of structure or a component in a machine to fail increased with the complexity of structure. This necessciated the analysis of the machine during design, a building before and after construction, to ensure proper functioning and reduce production losses. The analysis becomes difficult and time consuming as the complexity of the model increases. This dictated the need for an efficient method that gives a reasonably good result and require less time. Finite element methods give possiusible solutions to such problems and are much widely in use because the techniques can be adapted to digital computers.

ADVANTAGES OF FINITE ELEMENT METHODS

There are certain advantages of Finite Element Methods, which made it a widely used method. They are as follows:

1. With the advent of digital computers the analysis became cheaper, easier and faster.
2. Finite Element Analysis makes it possible to evaluate a detailed and complex structure in a computer during the planning stage itself. The demonstration in computer of the adequate strength of the structure and the possibility of improving the design during the planning stage justify the cost of analysis.
3. In the absence of Finite Element Analysis (or any numerical methods) designing and analysis of structures are based on hand calculations. Certain assumptions have to be made to reduce the complexity of calculations. This reduces the accuracy of solution. FEA makes effective use of numerical techniques, and even though some assumptions are made, the desired degree of accuracy can be achieved.

LIMITATIONS OF FINITE ELEMENT METHOD

1. FEA makes use of computers in solving equations. During this process many subtractions are done which ultimately decreases the accuracy of results. Problems of matrix conditioning appear here and the user of FEM must always bear in the mind the accuracy limitations, which do not allow the exact solution ever to be obtained.
2. Discretisation Error: In the finite element analysis, displacement functions are assumed which characterized each element. The choice of displacement functions depends on the ability of the user to adopt a polynomial type of function whose solution can be converged. If the displacement functions are chosen wrongly, the convergence of the solution cannot be obtained and the results shall be incomplete and inaccurate.

APPLICATION OF FINITE ELEMENT METHODS

The general nature of FE theory makes it applicable to a wide variety of boundary value problems. A boundary value problem is one in which the solution is sought in the domain of the body subject to the satisfaction of prescribed boundary conditions on the dependent variables or their derivatives. There are three major categories in the boundary value problems. They are:

1. Equilibrium or steady state or time independent problems.
2. Eigen value problems
3. Propagation or transient problems

In an equilibrium problem, we need to find the steady state displacement or stress distribution if it is a solid mechanics problem, temperature or heat flux distribution if it is a heat transfer problem and pressureor velocity distribution if it is a fluid mechanics problem.

In Eigen value problems time will not appear explicitly. These may be considered as extensions of equilibrium problems in which critical values of certain parameters like natural frequency or buckling loads and mode shapes if it is a structures problem, stability of laminar flows if it is a fluid mechanics problem etc., in addition to corresponding steady state configurations. The propagation or transient problems are time dependent problems. These cases arise if it is required to find out the response of a body under time varying force in the area of solid mechanics and sudden heating or cooling in the field of heat transfer.

6. Results and discussions of Heat exchanger with Brass pipes

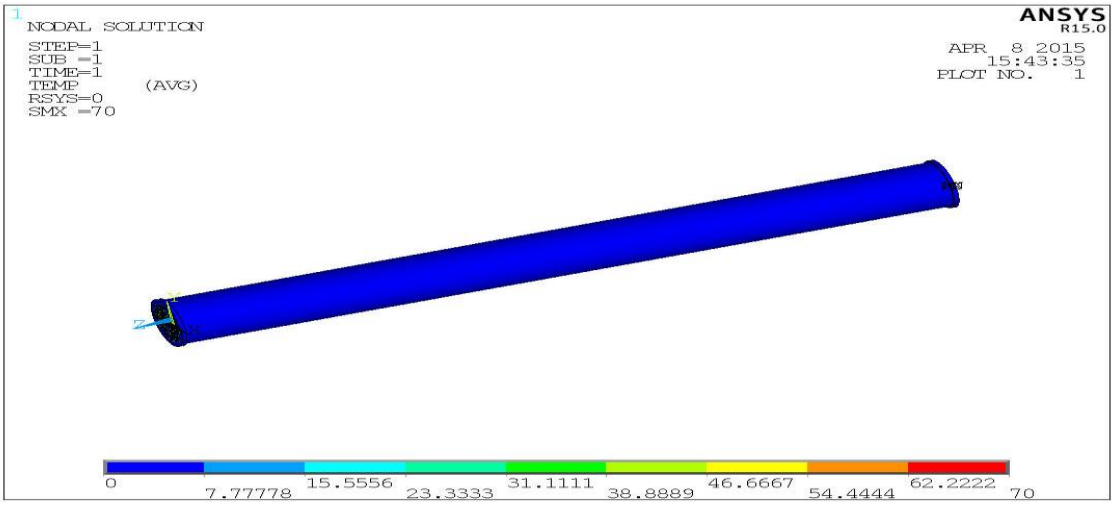


Fig. Nodal temperature of Heat exchanger

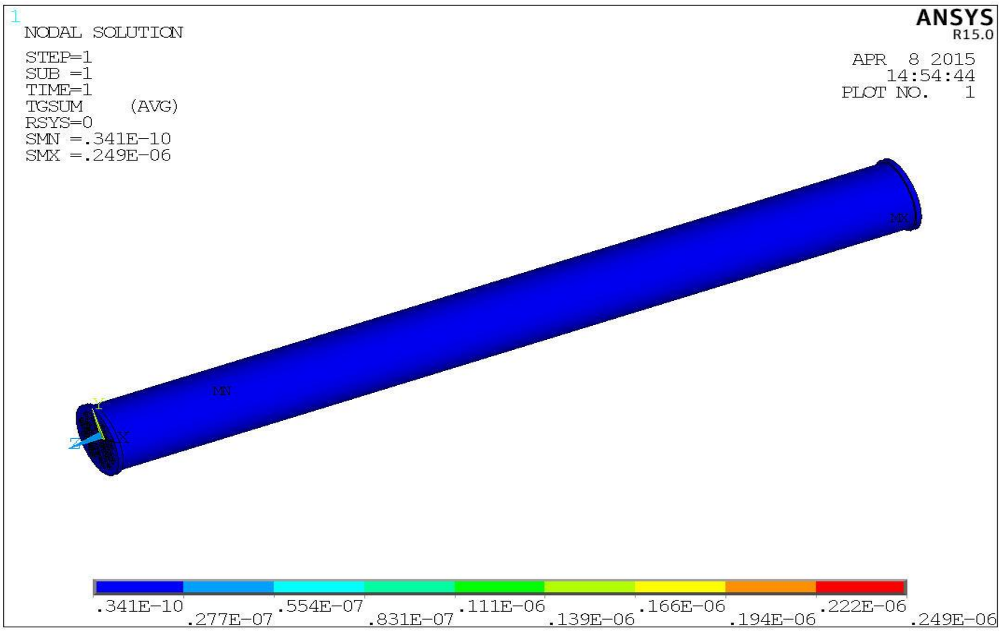


Fig. thermal gradient of Heat exchanger

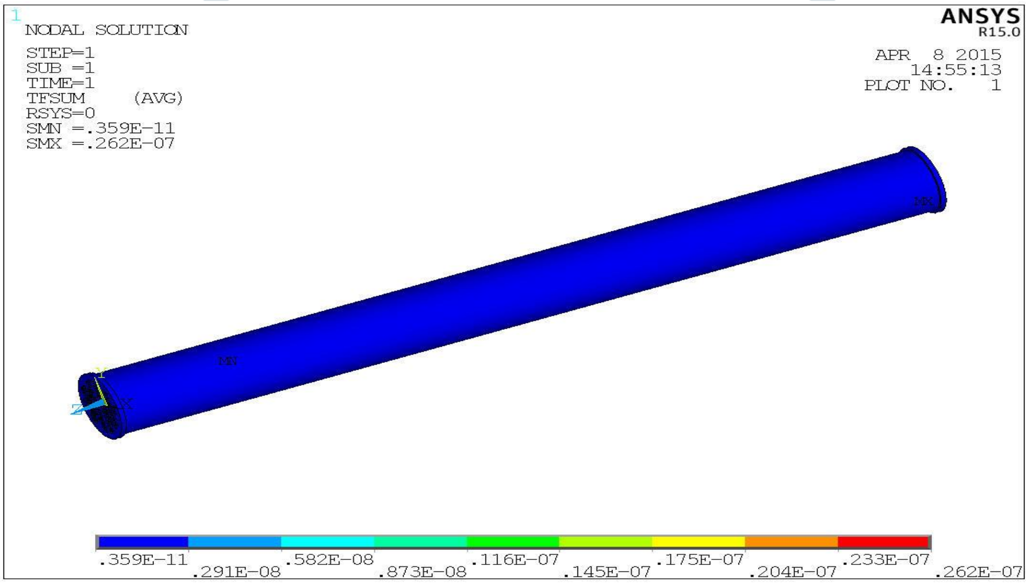


Fig. Heat flux of Heat exchanger

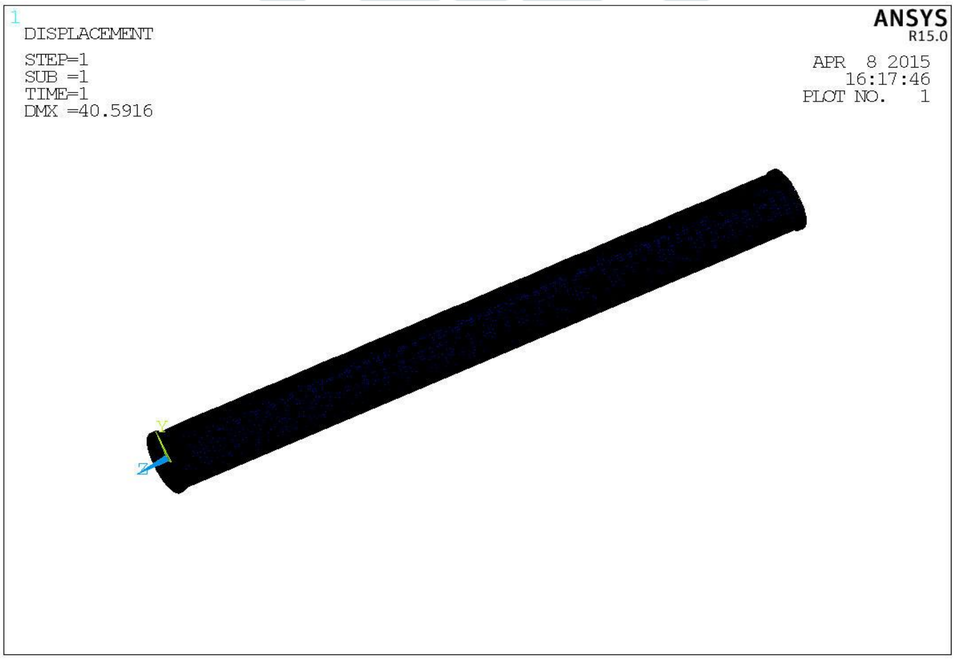


Fig. Deformation of Heat exchanger

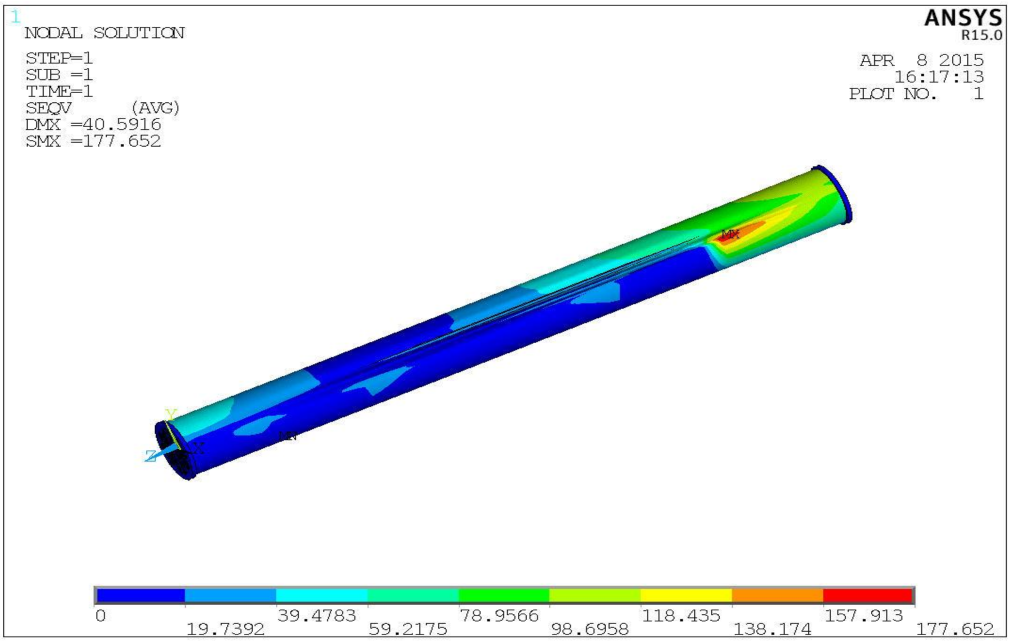


Fig. Vonmises stress of Heat exchanger

Results of Heat exchanger with copper pipes

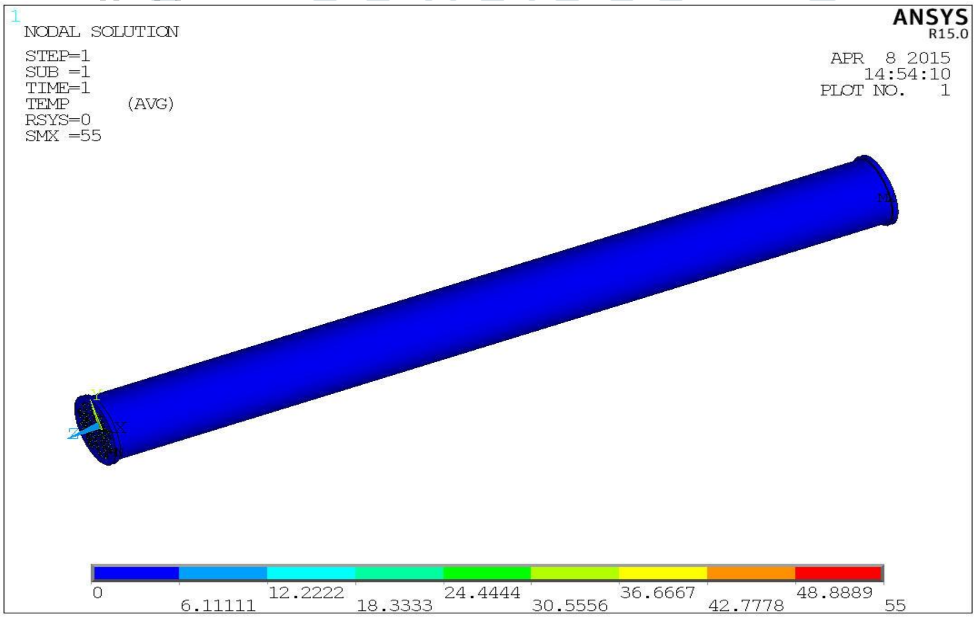


Fig. Nodal temperature of Heat exchanger

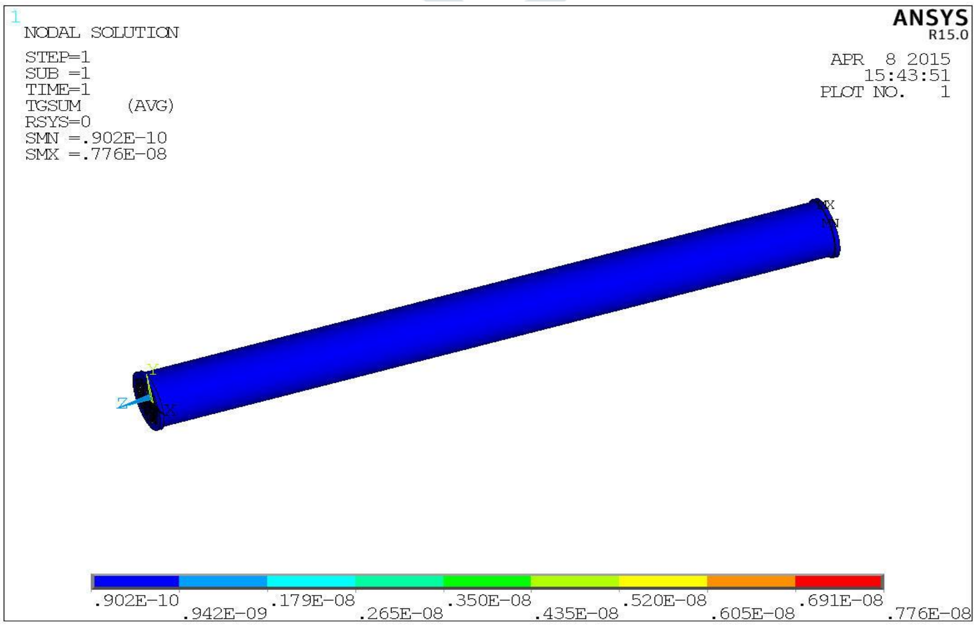


Fig. thermal gradient of Heat exchanger

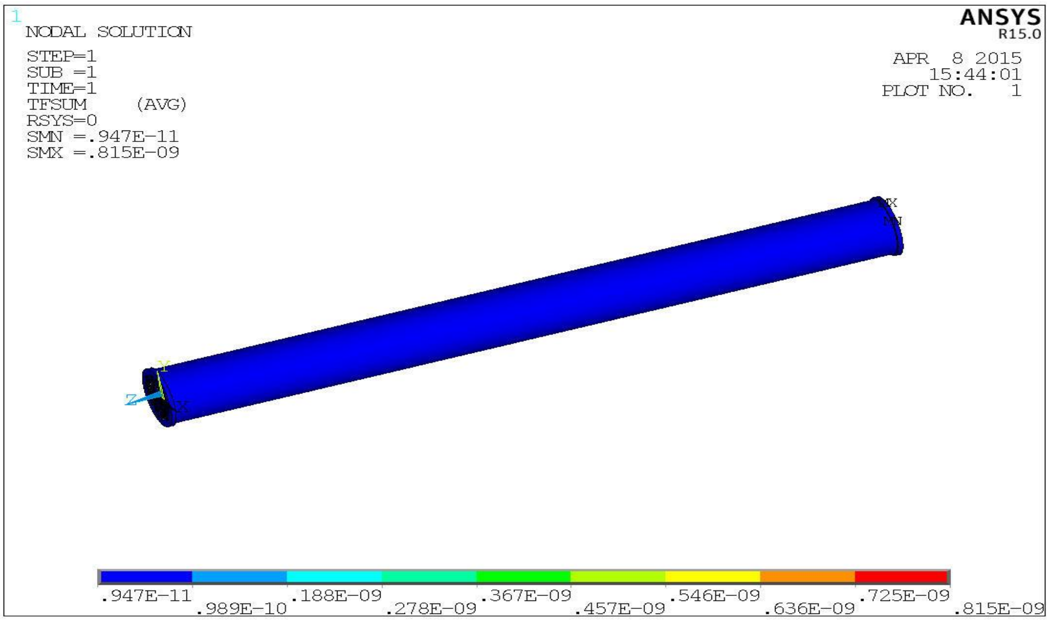


Fig. Heat flux of Heat exchanger

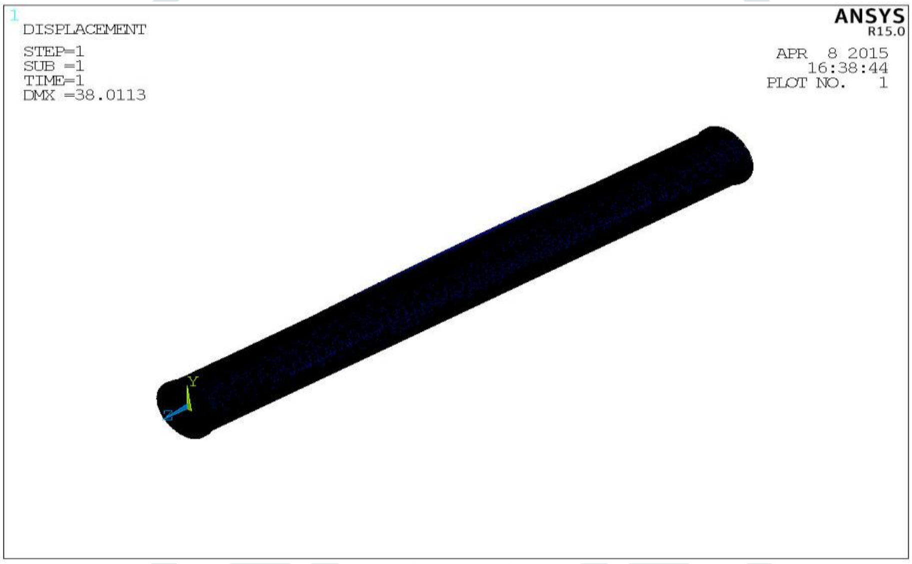


Fig. Deformation of Heat exchanger

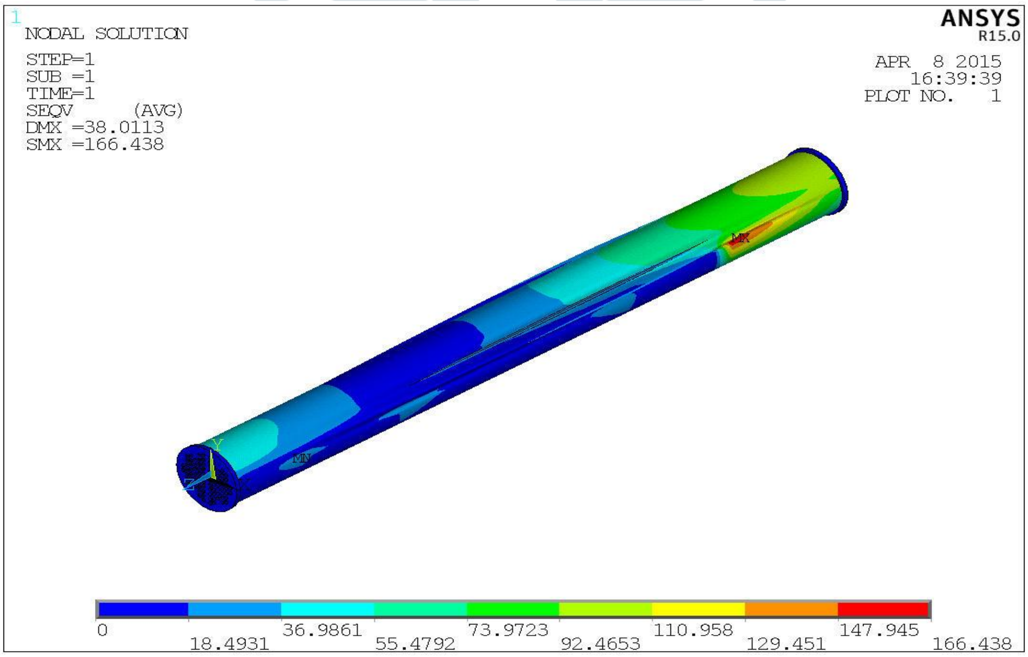


Fig. Vonmises stress of Heat exchanger

Tables shows results of heat exchanger with different Pipe materials

Parameters	Heat exchanger with Brass Pipes	Heat exchanger with Copper Pipes
Nodal temperature	70	55
thermal gradient	0.249e-6	0.776e-8
Heat flux	0.262e-7	0.815e-9
Deformation	40.5916	38.0113
Vonmises stress	177.652	166.438

Table

7. Conclusion

1. The thermal and pressure drop calculations for a given heat exchanger are done using theoretical equations. These results are evaluated with the world-renowned software package for design of heat exchanger “HTRI” (Heat Transfer Research Institute of USA).

2. In mechanical design, important minimum dimensions of different parts of the equipment to suit the design pressures and temperatures. The design standard ASME code for pressure vessel constructions are used.

3. The maximum Von Mises stress induced is **166.438Mpa and 177.652Mpa** which is less than allowable stress. Hence the design is safe based on the strength

4. From the theoretical modeling the convection heat transfer coefficients along with the bulk temperature and imposed as a boundary conditions to predict the temperature distribution in heat transfer analysis in both the shell and tube.

5. Nodal temperatures are also less for both materials. Finally we conclude that the Heat exchanger with copper pipes is better than Heat exchanger with Brass pipes.

8. References

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